



RESEARCH DEPARTMENT



REPORT

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# **DIGITAL TELEVISION TRANSMISSION: 34 Mbit/s PAL investigation**

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PAL INVESTIGATION**

**P.A. Ratliff, Ph.D., B.Sc., J.H. Stott, M.A.**

**Summary**

*The use of digital techniques for transmission has well-known advantages. However, transmission of video signals in digital form may not be economically attractive unless bit-rate reduction methods are used. Suitable methods are reviewed and three of them discussed in greater detail. The use of these methods is illustrated by the description of a system which conveys a broadcast-quality video signal, together with two high-quality sound signals and other ancillary services, within a total bit rate of 34 Mbit/s.*

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# DIGITAL TELEVISION TRANSMISSION: 34 MBIT/S PAL INVESTIGATION

P.A. Ratliff, Ph.D., B.Sc., J.H. Stott, M.A.

## 1. Introduction

The advantages of digital transmission are well known, namely that digitally-coded signals are inherently highly resistant to the effects of noise and distortion encountered in transmission systems and can be regenerated for long-distance transmission. Accordingly the quality of television signals (video and audio) transmitted in digital form is usually determined by the coding methods used rather than the link itself. Digital transmission of video signals is therefore attractive, the more so as other factors come into play. British Telecom is currently developing a UK digital telecommunications network in which digital television could take its place alongside telephony and data without special treatment. Indeed, the provision of analogue video links is becoming the special, and thus more expensive, case. At the same time, as increasing use is being made of digital techniques for programme origination, digital transmission between studios or to broad-

cast transmitters would form a logical step in the process of evolution towards all-digital operation.

However, straightforward digital coding of a video signal generates a signal having a high bit rate (over 100 Mbit/s) which, if transmitted, is rather wasteful of channel capacity. Possible ways of reducing the bit rate required for video signals have therefore received much attention. Previous work in Research Department produced an experimental system which has been used in several field trials of digital transmission<sup>1,2,3</sup>. One video signal and six high-quality sound channels were coded and multiplexed into a 60 Mbit/s "package"; two such packages could be multiplexed into 120 Mbit/s.

To be useful a package must provide a suitable combination of video and other signals within a bit rate at which access to the telecommunications digital network is permitted. The figures of 120 and 60 Mbit/s mentioned above were appropriate for the experimental digital cable and satellite

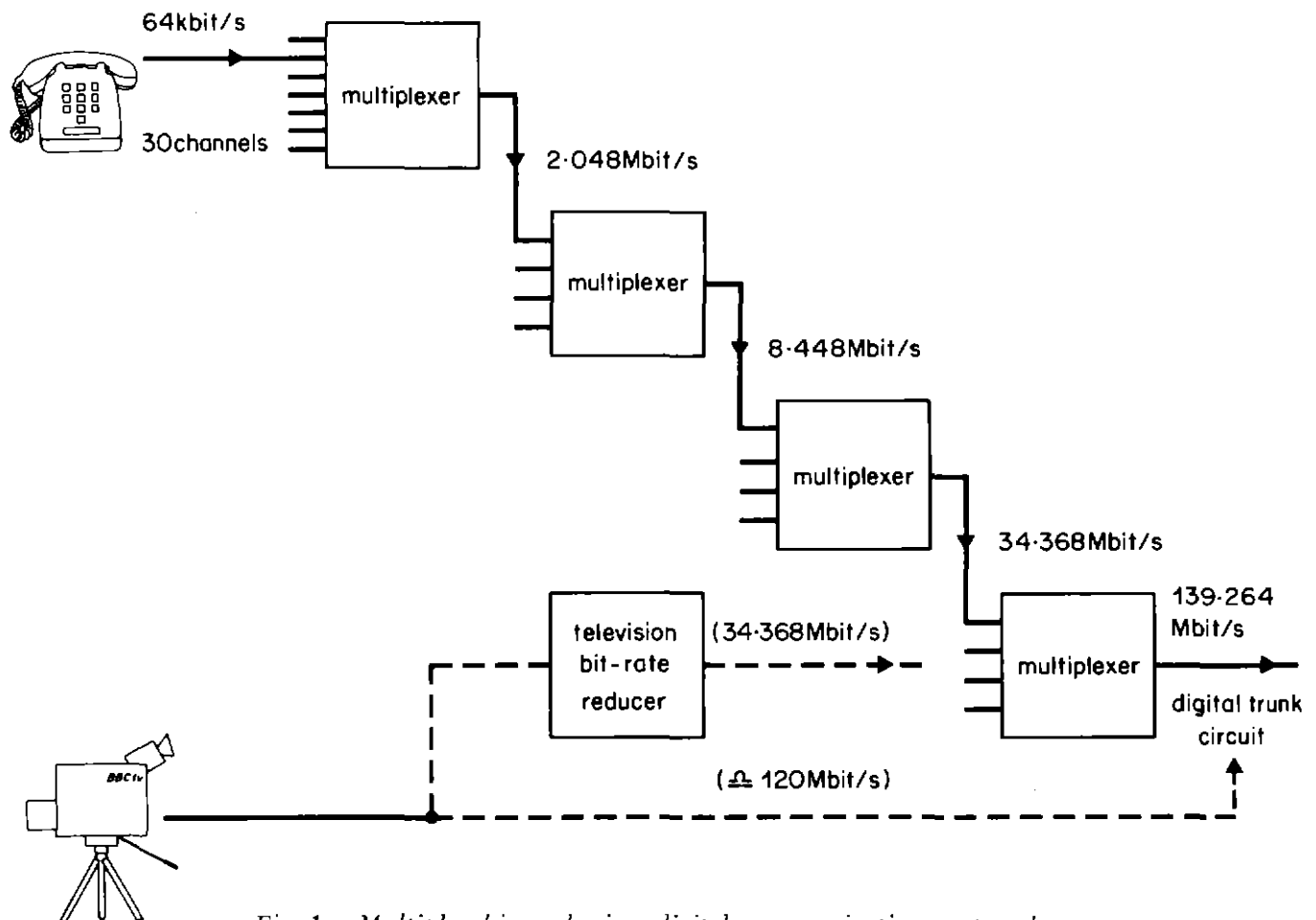


Fig. 1 — Multiplex hierarchy in a digital communications network.

systems of the time, but since then a hierarchy of bit rates has been agreed within Europe. This uses the following bit rates: 2.048, 8.448, 34.368 and 139.264 Mbit/s. It is shown in Fig. 1. 139.264 Mbit/s (commonly called "140 Mbit/s") may not be universally available in Europe, while in the UK access may also be arranged at 68.736 Mbit/s ("68 Mbit/s") which is exactly twice 34.368 Mbit/s ("34 Mbit/s").

An obvious target for the next stage of bit-rate reduction studies was therefore 34 Mbit/s. This appeared to be attainable using techniques which were an extension of previous BBC experience. The knowledge gained would also be useful for other, higher, bit rates if they proved to be economically more attractive, bearing in mind the balance between circuit and equipment costs. Conversely, to reduce the bit rate of a broadcast-quality video signal to fit within say 8 Mbit/s would undoubtedly require much more advanced techniques.

This Report gives a broad description of an investigation into techniques suitable for the development of a 34 Mbit/s package. The techniques are discussed in greater detail in companion Reports <sup>4,5,6</sup>.

## 2. Choice of techniques

There are two basic approaches to digital coding of colour television signals: either to code the composite colour signal directly or to code its components, usually the luminance and two colour-difference signals, separately. For maintenance of the highest quality during the production of the television programme, separate component coding is now favoured because of the flexibility that it affords. The EBU, and subsequently the CCIR, have established a common world-wide digital coding standard based on separate components; it specifies sampling rates of 13.5 MHz for luminance and 6.75 MHz for the two colour-difference components. The resulting total bit rate exceeds 200 Mbit/s, but, within a studio, the added flexibility outweighs this disadvantage. However, for signal distribution, efficient use of bandwidth is much more significant and importance must here be placed on minimising the required bit rate.

Where efficient compression is the principal criterion, the choice of whether to code composite or separate component signals is not clear cut. PAL and NTSC composite colour signals are suited to the requisite digital processing because it is possible to take account of the modulated chrominance, but this is not the case for SECAM signals.

Only limited attempts have been made to compress the digitised SECAM signal<sup>7</sup>.

Many workers have opted for separate component coding methods since it ostensibly permits compression techniques to be better matched to the physiological properties of the eye. However, the digital PAL signal is particularly amenable to bit-rate reduction, and, given that the television signal has to be transmitted in PAL form to the general public in the United Kingdom, the best compromise between high quality and low bit rate may be obtained by processing the PAL signal directly. The chrominance information may be carried within the same bit rate required for the luminance information alone, and only one processing chain is required. In the separate component approach, on the other hand, three separate processes are required, and some workers have had to develop complex interactive techniques to minimise the combined effects of the distortion products of separate bit-rate reduction processes operating in parallel.

By the time that studio centres are able to accept and deliver digital component signals, there will be a requirement to inter-connect them using component-based contribution links, despite the additional complexity involved, and work is currently in hand to develop systems suitable for this. For distribution to transmitters, however, where further 'downstream' processing is not required, composite-based systems will continue to be appropriate.

Over the last decade a considerable amount of work has been conducted at BBC Research Department into various techniques for bit-rate reduction of the composite PAL signal. Studies of the statistical redundancy in the signal <sup>8,9</sup> have shown that a significant saving in bit rate could be made using variable-length coding, of perhaps 50% or more, for many pictures. However, some picture sequences contain relatively little redundancy, and it would require an enormous buffer store to smooth out the transmission rate sufficiently to take advantage of the possible gains. Also, efficient variable-length codes have very poor immunity to transmission errors. On the other hand, removal of the highly-redundant television blanking intervals does not require variable-length coding. Moreover, this effects a significant bit-rate saving with good error immunity and does not impair the picture quality <sup>10</sup>.

DPCM<sup>11</sup> and Hadamard Transform coding<sup>12</sup> methods have also been studied at length, and

Clarke demonstrated that, for a given bit rate and using relatively simple implementation of each technique, DPCM was consistently better for high-quality pictures<sup>13</sup>. He concluded that, for a similar degree of equipment complexity, improved DPCM was likely to remain better than improved transform coding, and this has been subsequently confirmed by other workers<sup>14</sup>. More recently the development of the Cosine Transform<sup>15</sup> looks more promising,<sup>16</sup> but workers in this field tend to favour it, in comparison with DPCM, at very low bit rates where the distortions associated with each approach have a different subjective significance.

Additionally, it was found that the composite PAL signal could be sub-sampled, below the Nyquist rate, without serious problems arising from the overlapping of the baseband and the sampling spectra<sup>17,18</sup>.

Thus, it was decided that the present investigation should be based on bit-rate reduction of a composite PAL signal.

Three techniques were selected for further study, the aim being to reduce the bit rate required for broadcast-quality video signals to about 30 Mbit/s, so that the system parameters for a 34 Mbit/s "package" of video, sound and ancillary services could be specified. The techniques are:

(a) Blanking-interval removal;

(b) Sub-Nyquist sampling;

and (c) DPCM.

In addition, consideration had to be given to requirements for ancillary signals, error correction and multiplexing.

### 3. Blanking-interval removal

The inclusion of considerable periods of waiting time in-between transmitting useful picture information seems a flagrant misuse of channel capacity, yet was largely determined by the requirement for cheap scanning circuits in domestic receivers and the inability to store a whole television field economically. Given the existence of such large overheads it is obvious that these blanking intervals should be removed in point-to-point digital transmission, but be reinserted before broadcasting to the general public.

Fig. 2a shows the essential elements of a blanking interval remover. After making measurements on the incoming video signal, the central

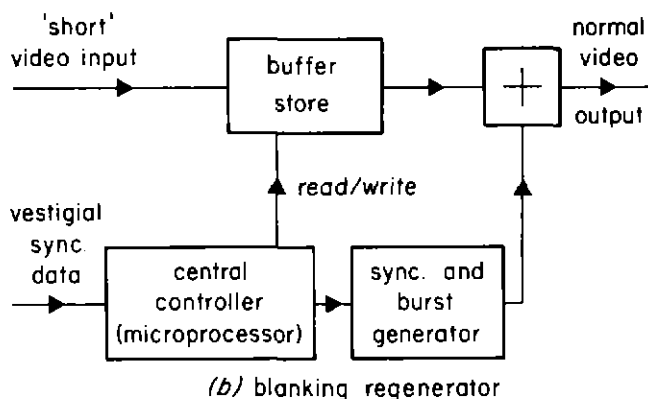
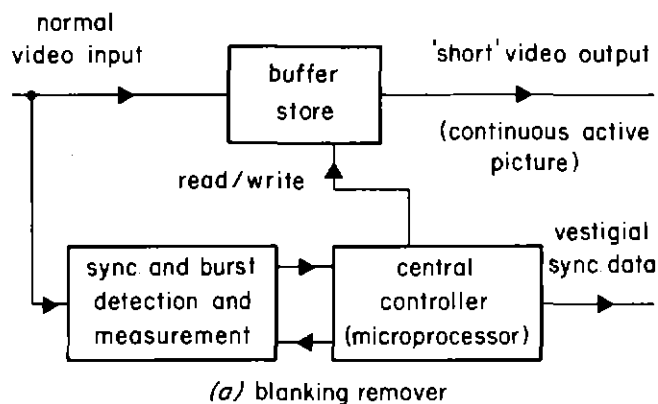


Fig. 2 — Blanking interval removal codec.

controller writes the video signal into a buffer store during active-picture periods only. However, it reads the video signal out of the buffer store at a continuous, but appropriately reduced rate. At the blanking regenerator (Fig. 2b), the reverse process occurs with the controller also operating the blanking waveform generator to fill in the gaps in the output picture signal, thus reconstructing a standard video signal.

The technique is, of course, applicable to all television coding systems with more or less equal effect, giving some 18% saving in bit rate if line-blanking intervals are removed and about 24% saving if both line- and field-blanking intervals are removed. Fig. 3a shows the blanking intervals in a normal video signal and Figs. 3b and 3c show the blanking-removed signal on a conventional monitor (3b) and on a specially-adapted monitor (3c), which shows that only the active-picture information remains.

An alternative method is possible, in which the blanking intervals are identified and overwritten with the data from sound channels, etc. This avoids the need for a video buffer store since the instantaneous video bit rate is unaltered, but a

blanking waveform regenerator is still required at the receiver. This method is suitable in some circumstances depending on the relationship and relative stability of the various input and output bit rates of the system.

The blanking waveform regenerated at the digital receiving terminal is synchronised to the picture signal by the transmission of vestigial synchronising data. In the ideal digital world, with precisely-defined blanking intervals, a code transmitted only once per field or picture would be sufficient to maintain synchronisation. However, the analogue signals at the input to the digital link may sometimes exhibit a departure from the ideal specification, and it is desirable to ensure that the digital blanking-waveform regenerator at the receiving terminal reproduces a close replica of the blanking waveform removed at the digital transmitting terminal. Measurements of the input synchronising pulse and burst amplitudes, and their relative timings, are made and transmitted in a rugged manner, this occupying about 1% of the transmitted bit rate.

A net saving in bit rate of 23% is achieved by the method proposed for a 34 Mbit/s system, in which both line- and field-blanking intervals are removed. Further details are given in the companion Report<sup>4</sup>.

#### 4. Sub-Nyquist sampling

Conventionally, the composite PAL colour signal is sampled at three times the colour subcarrier frequency, at about 13.3 MHz, which is somewhat above the theoretically-required Nyquist rate of 11 MHz. The difference provides a margin for the finite roll-off of practical baseband filters, and the choice of a harmonic of subcarrier frequency minimises the visibility of any intermodulation products introduced in the analogue-to-digital converter (although with improvements in converter design the latter is becoming less of a problem). A total of 256 quantising levels, linearly disposed and defined by an 8-bit sample, is generally considered to be necessary to convey sufficient accuracy. This, associated with the 13.3 MHz sampling frequency, gives rise to a bit rate of about 106 Mbit/s. Similar methods applied to component coding require an even greater bit rate; the coding system agreed by the EBU requires at least 216 Mbit/s.

However, it has been shown that with the composite PAL signal, the sampling rate can be substantially reduced, to the sub-Nyquist rate of only twice the colour subcarrier frequency ( $2f_{sc}$ ),

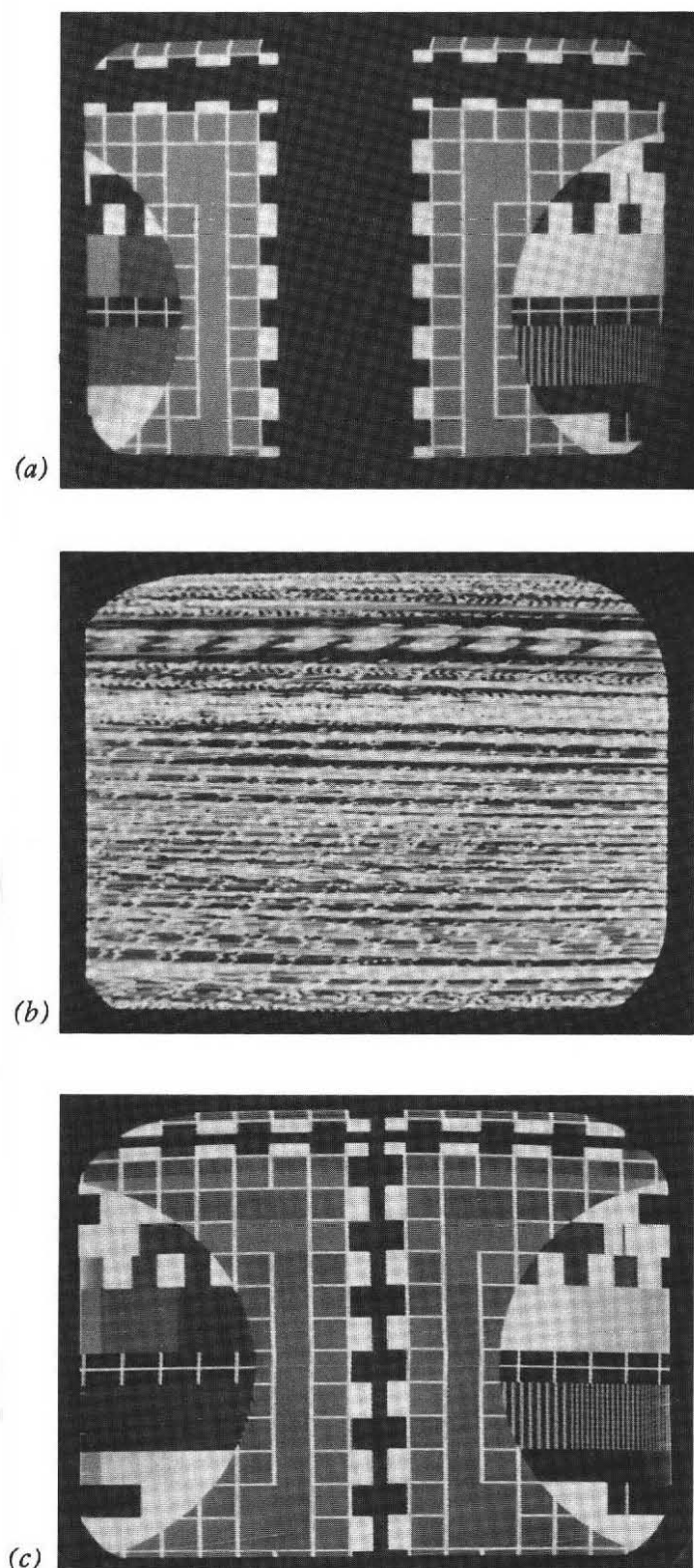


Fig. 3 — Test-card pictures artificially displaced to show blanking intervals.

- (a) Normal picture signal
- (b) Picture signal with blanking removed ('short' video)
- (c) Picture signal with blanking removed and viewed on specially adapted television monitor.

about 8.86 MHz, with minimal loss of picture quality<sup>17</sup>. The analogue signal is first sampled at the super-Nyquist rate of four times the colour subcarrier frequency ( $4f_{sc}$ ). This is then halved by the action of an appropriate digital comb filter in the high-frequency part of the spectrum, to take account of the unwanted or alias components thus introduced (Fig. 4a). The filtering process consists of reducing the  $4f_{sc}$  sampling structure to a  $2f_{sc}$

unified phase on alternate television lines (as shown in Fig. 8).

At the decoder (Fig. 4b), a similar filter is used prior to the digital-to-analogue converter to re-establish the conventional PAL signal. This filter separates the high-frequency luminance from its alias and combines the unified-phase chrominance components to reform the con-

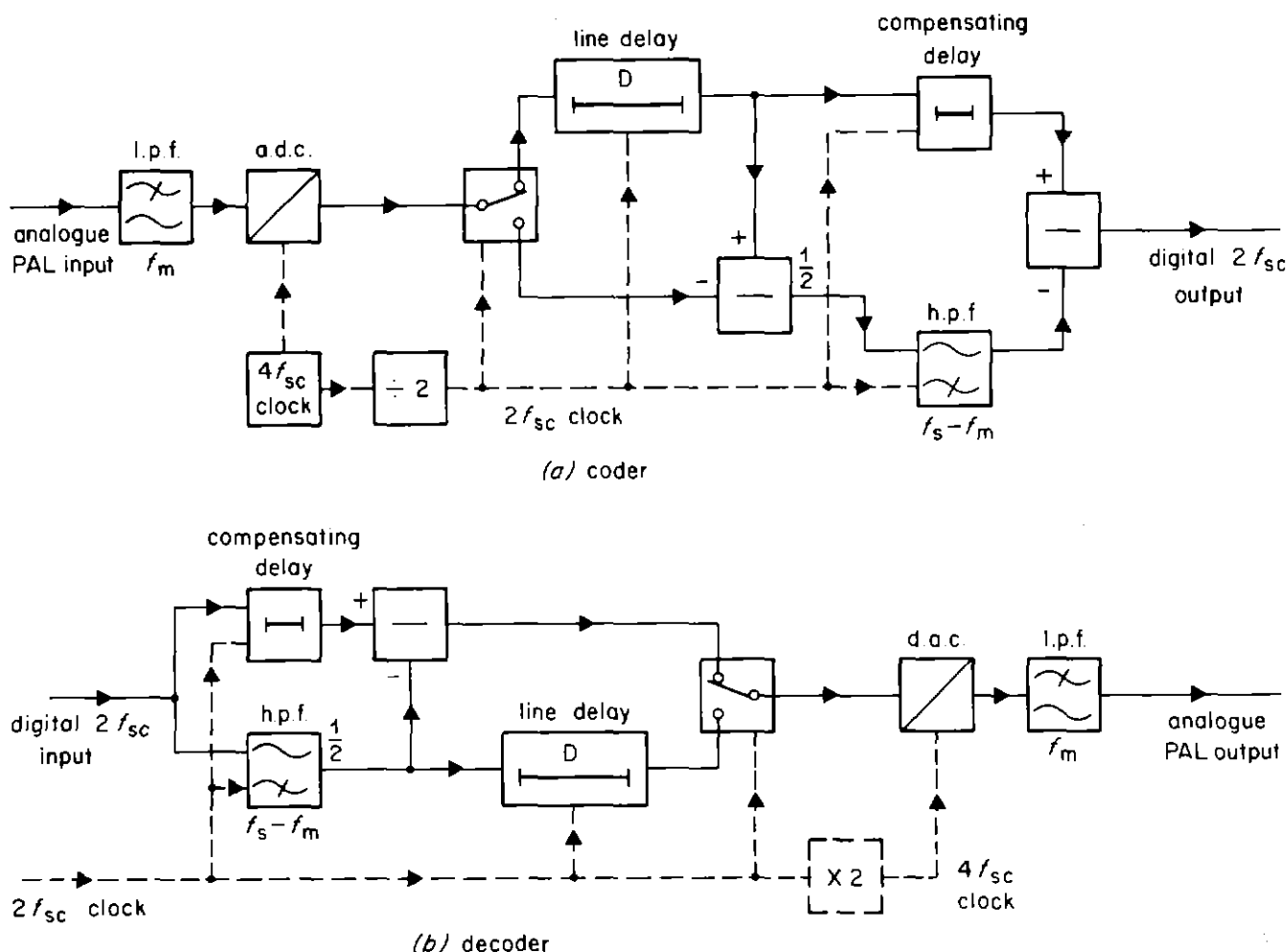


Fig. 4 — Sub-Nyquist sampling codec.

structure by taking alternate ( $4f_{sc}$ ) samples and averaging them with the alternate, but interleaved, samples from the previous television line. This has the effect of confining the high-frequency luminance to its predominant frequencies about multiples of line frequency,  $nf_H$ , such that its alias components interleave, being concentrated about odd multiples of half line frequency,  $(n+1/2)f_H$  (See Fig. 5). In addition, the phase of the initial  $4f_{sc}$  sampling is chosen such that the chrominance alias components reinforce the modulated chrominance components ( $u, v$ ) in the filter (Fig. 5). The chrominance is thus transformed into sum and difference modulation components ( $u+v, u-v$ ) with

ventional ( $u, v$ ) modulated PAL chrominance signal.

The main effects of sub-Nyquist sampling are to reduce luminance resolution on diagonal transitions and chrominance resolution on horizontal transitions. However, the latter is not normally significant, since the chrominance bandwidth of the normal PAL system restricts the resolution on vertical transitions to a greater extent.

These effects are best illustrated in the 'coding loss' picture of Fig. 6. The output of the sub-Nyquist sampling decoder has been subtracted from the input to the coder (for Test Card F signal)

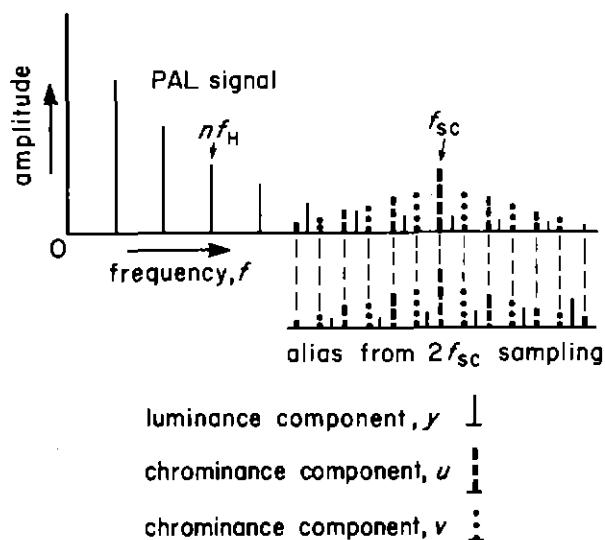


Fig. 5 – Spectrum of composite PAL signal and its alias from  $2f_{sc}$  sampling.

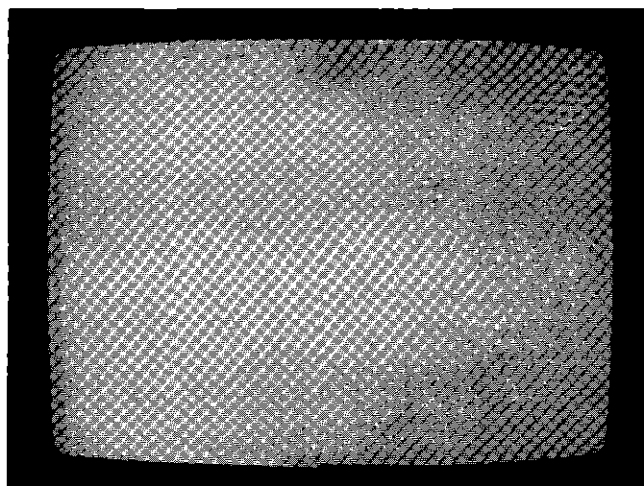


Fig. 6 – 'Coding loss' introduced by sub-Nyquist sampling. (Some of the 'loss' is the unwanted cross-colour in the original PAL signal and hence provides an improvement in picture quality, e.g. the patterns in the diagonal bars of the test-card picture).

and the difference displayed on a television monitor, with mid-grey representing zero loss. However, it is interesting to note that some of the so-called 'loss' is, in fact, a reduction in the unwanted 'cross-colour' components present in the normal PAL signal!

This coding loss is very small, but other refinements were still investigated to try to reduce it further. Instead of averaging the  $4f_{sc}$  samples across a line period, the delay,  $D$  in Fig. 4, can alternatively be a field period (313 lines), or even a picture period (625 lines). In the latter case, no loss of resolution occurs at all on stationary

pictures, but severe blurring occurs on moving transitions. The use of field delays halves the static resolution losses of the line-delay system and the movement blur of the picture-delay system. It was hoped that this might represent a better compromise between static and dynamic resolution loss. However, subjective tests showed that the impairment of moving colour transitions was still unacceptable. It is considered more profitable to refine the line-delay system, by careful shaping of the transition between combed and uncombed parts of the spectrum. Moreover, a slightly more complicated configuration of filter than that shown in Fig. 4 gives benefits if coding systems are used in cascade.

These refinements and the detailed assessment of their performance are discussed in Reference 5.

## 5. Differential pulse-code modulation (DPCM)

The number of quantising levels required for the video signal may be reduced by differential encoding. This is a very popular bit-rate reduction technique and relies on the considerable degree of redundancy within the television picture signal. A fairly good prediction of the signal can be made from previously transmitted information, and the transmitted signal comprises the error between the predicted and the true signal. Fig. 7 shows a block diagram of a DPCM codec.

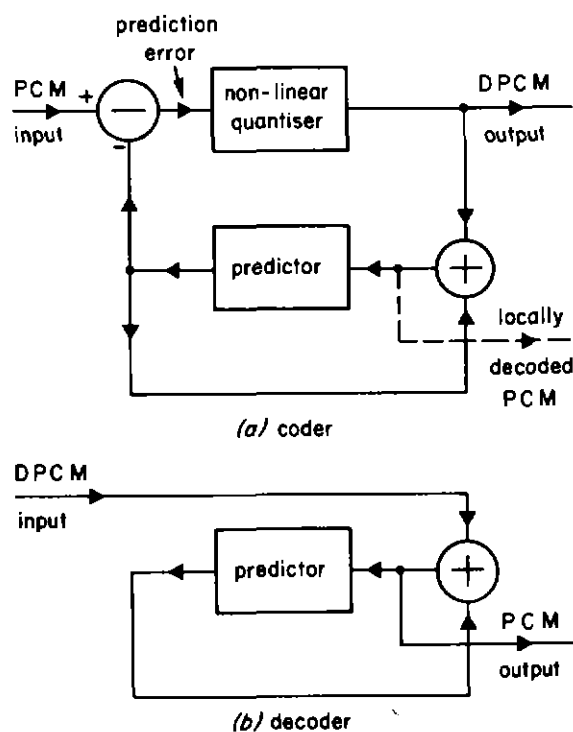


Fig. 7 – DPCM codec.

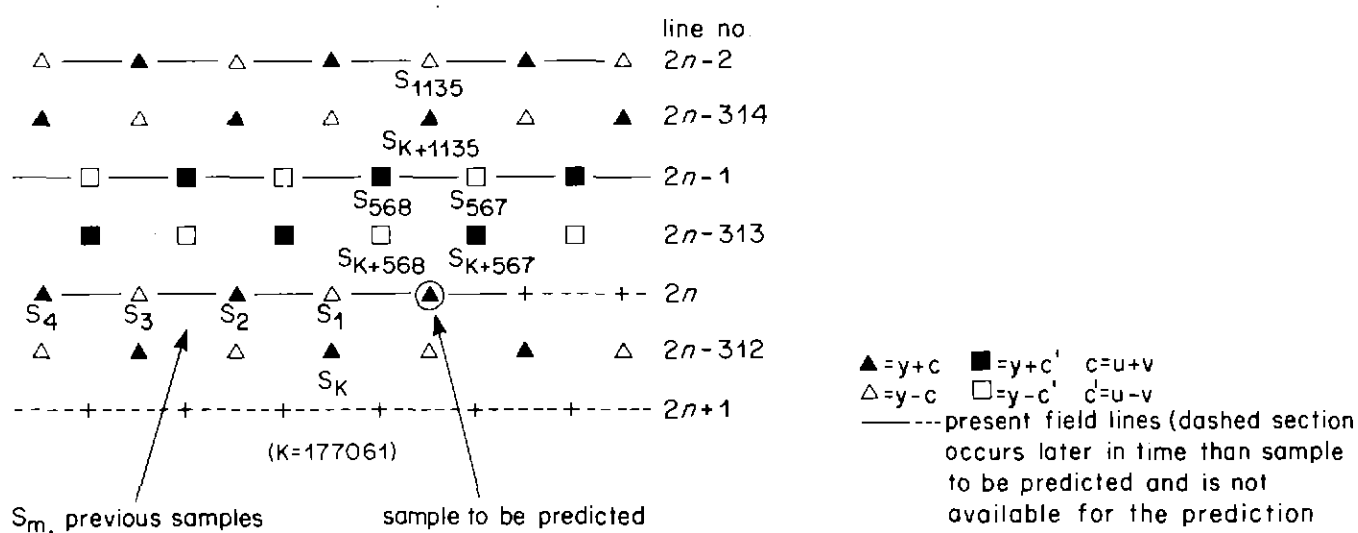


Fig. 8 —  $2f_{sc}$  sampling structure.

Statistically, the prediction error is small and can be substantially conveyed using a reduced number of quantising levels. Only when the picture is highly detailed does it become difficult to predict and give rise to large prediction errors. However, these large errors may be conveyed with reduced accuracy, since the eye is more tolerant to quantising inaccuracy in high-amplitude, fine-detail picture areas. The prediction-error signal is therefore subjected to non-linear quantisation before transmission, small differences being conveyed with full accuracy and larger differences with progressively reduced accuracy. Thereby, the total number of quantising levels required may be significantly reduced without introducing large subjective impairments.

With the composite PAL signal, the problem is how to apply the DPCM technique such that no loss of accuracy occurs in plain coloured areas. This is where the eye is most sensitive to contouring effects produced by insufficient quantising accuracy. The solution is to make a predictor which is good for steady-state chrominance modulation as well as DC. Fig. 8 shows the  $2f_{sc}$  sampling structure in a plain coloured area for one television picture. It can be seen that a simple prediction which satisfies this criterion is the second-previous sample value,  $S_2$ <sup>17</sup>. However its luminance frequency response is somewhat limited, and only a modest bit-rate saving can be made without generating perceptible impairments on critical pictures. A 6-bit non-linear quantising law has been used successfully in experimental digital-television transmission equipment operating at 60 Mbit/s<sup>1</sup>.

For greater compression, a more highly-tapered quantising characteristic must be used. Television transmission at 34 Mbit/s requires that the video signal be reduced to about 31 Mbit/s to allow sufficient capacity for sound, ancillary signals and error-protection coding. Assuming sub-Nyquist sampling and full blanking-interval removal, this permits a mean of  $4\frac{1}{2}$ -bits/sample to be transmitted (in practice, one 9-bit word represents two sample values). Thus the DPCM quantiser can have only 22 states, and such a characteristic may be seen displayed on the television monitor in Fig. 9, which also shows the experimental equipment.

It therefore follows that the prediction must be improved to provide a more highly-peaked distribution of the prediction error. An appropriately-weighted sum of the sample values back along the television line gives some improvement, but a prediction gain (the ratio of the mean-square prediction error for the predictor to that for the simple second-previous sample predictor) of only about 2 dB may be realised. Greater gains can be achieved by spreading the prediction into two dimensions, but normally the action of the  $v$ -axis switch, present in the PAL signal, complicates the use of samples in the previous line, necessitating the use of an adaptive predictor. However, the sub-Nyquist sampling technique unifies the phase of colour subcarrier (in a plain coloured area, see Fig. 8) so that samples in the previous line can be used in a static predictor, although they do not contribute usefully to the chrominance prediction. Prediction gains of about 4 dB have been measured, but this is still not

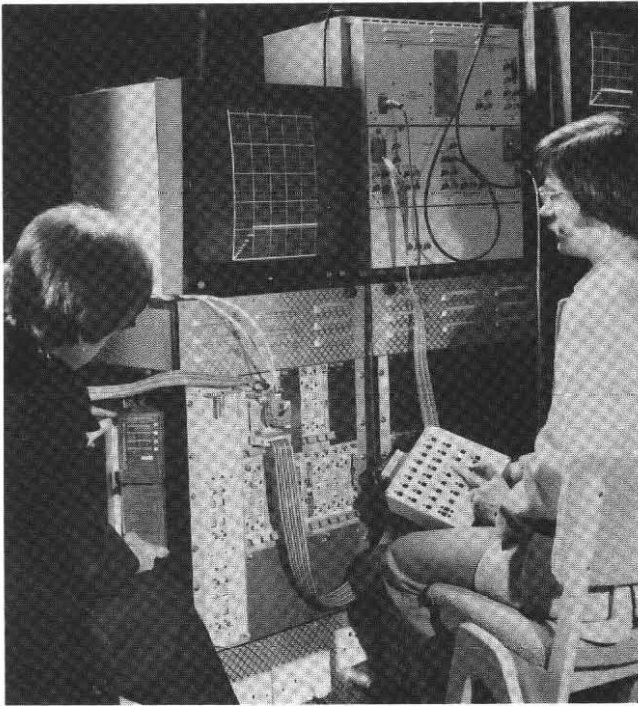


Fig. 9 — Equipment for the study of video bit-rate reduction using sub-Nyquist sampling and complex DPCM. (The video monitor is displaying a 22-level, non-linear quantising law corresponding to the  $4\frac{1}{2}$  bits/sample available for 34 Mbit/s transmission).

enough to provide broadcast-quality pictures with a  $4\frac{1}{2}$  bits/sample quantiser. However, if the previous-field samples are also stored, access to the interlaced lines on both sides of the sample to be predicted is obtained. For stationary pictures a prediction gain of about 8 dB over the simple second-previous sample predictor may be achieved, by using the temporal dimension to improve the spatial resolution. Picture movement, however, may be expected to reduce this gain.

A prediction algorithm, involving the use of previous samples from the same line, from previous lines in the same field, and from a previous field, is known as a three-dimensional (3D) predictor.

Initially, the sample weights in the prediction algorithm were computed using a simple statistical model of the television signal, assuming it to be a first-order Markov source. However, because of the modulated chrominance of the PAL signal, an additional constraint was added in the computation of the sample weights of 'optimum' predictors, requiring steady-state colour to be predicted correctly. Thus the conditions which must be satisfied are:

- (a) the sum of the predictor coefficients (sample weights,  $S_m$ ) equals unity
- (b) the sum of the even coefficients minus the sum of the odd coefficients on even lines equals unity
- and (c) the sum of the even coefficients minus the sum of the odd coefficients on odd lines equals zero

where the sample to be predicted is considered to be even on an even-numbered line,  $2n$ .

A fixed temporal aperture was also assumed when computing 3D predictors and a previous-field correlation factor was determined empirically to be in the range of 0.8 to 0.9 for normal moving pictures.

The model gave quite good results on typical test pictures but was optimistic in its calculated prediction gains for pictures with large amounts of luminance detail and little chrominance.

Subsequently it became possible to transfer digital video signals to a computer for statistical analysis. 'Optimum' predictors were computed by minimising the mean-square prediction error, subject to the constraints listed above, for a range of standard test slides chosen to represent normal broadcast pictures. A further refinement was to modify the constraints to reduce the chrominance gain (found subjectively to give a better-balanced compromise) and to introduce a 'leak' as discussed later in Section 6. The resulting predictors were found in subjective tests to give the best results for the number of coefficients used, and a 14-sample predictor, comprising samples from three lines in each field, gives remarkably good results. Fig. 10 shows that the amplitude of the prediction error is small for the whole of the test card picture. The corresponding prediction algorithm is shown in Fig. 12.

The non-linear quantising characteristic was initially derived by minimising the mean-square quantising error, but this gives a somewhat too tapered shape, and final optimisation was achieved subjectively.

It has been found that a complex mixed-field predictor is admirably well suited to the characteristics of the human visual system. On stationary pictures and for slow movement, the prediction error remains small, such that the loss introduced by the non-linear quantiser is virtually imperceptible. In fact, it is only by subtracting the system output from its input and displaying the difference on a television monitor, as shown

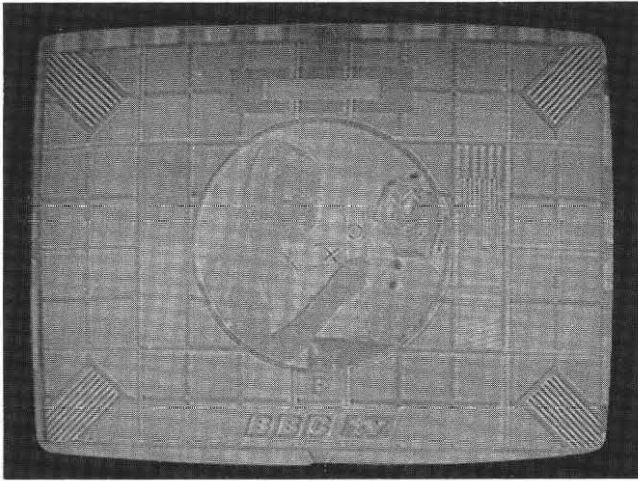


Fig. 10 — Prediction error for complex, 14-coefficient, mixed-field prediction.

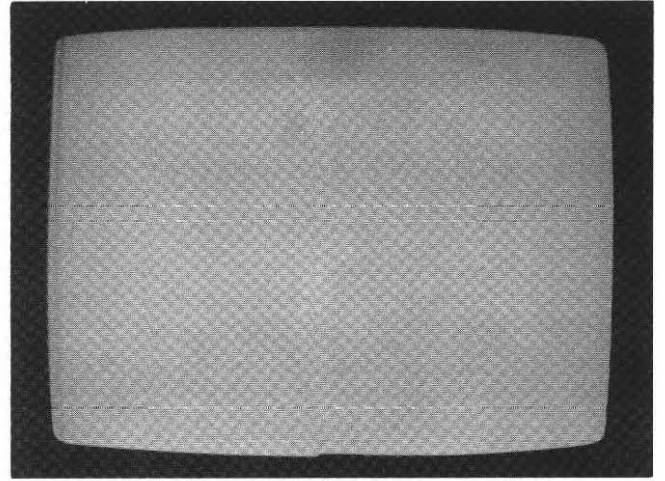


Fig. 11 — Coding loss for 4½-bit, complex-prediction DPCM\*.

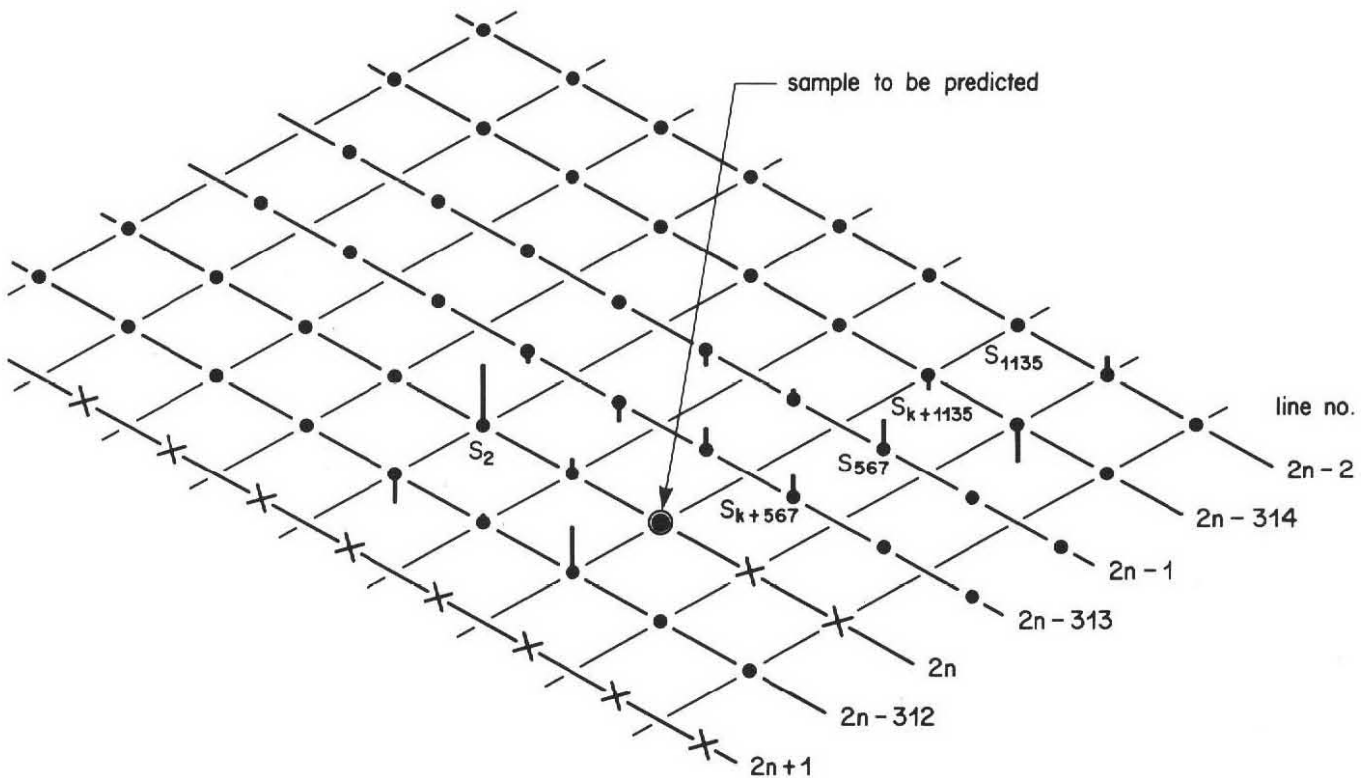


Fig. 12 — Isometric diagram showing the sample weights of a complex 3D predictor.

in Fig. 11, that we know where to look for any loss! As movement speed is increased, significant quantising errors appear on the loss pictures, but on the actual decoded pictures the movement is such that the eye is not able to resolve the loss of resolution of the moving transitions.

Many workers have used a spatially-coincident, previous-picture sample as a prediction for low bit-rate video systems, but, in contrast, we have found that use of previous-picture samples,

either alone or in a mixed-picture predictor, gives rise to severe movement blurring and would require movement-adaptive techniques to be useful for high-quality broadcast pictures.

The necessity of using rather spread predictors, and in using previous-field samples rather than previous-picture samples, has proved a considerable advantage in designing a static three-

\* Some loss is just apparent in the original photograph.

dimensional predictor for the PAL signal. It provides sufficient gain to be able to reduce the number of quantising levels to 22 in the DPCM system, with negligible subjective loss in quality.

So far we have been concerned with the design of a DPCM codec to achieve a satisfactorily small coding loss. However, another important aspect is the behaviour of the system in the presence of transmission errors. This is discussed briefly in the next Section and in more detail in the companion Report<sup>6</sup> dealing with DPCM.

## 6. Transmission performance

In any proposed transmission system the effects of transmission errors must be carefully considered. A problem often encountered when redundancy-reduction techniques are used is that the removal of signal redundancy also removes the ruggedness to transmission errors which may occur in a practical system. The deliberate addition of a little redundant information in the form of error-correction coding can give a better match of the channel characteristics to those required by the signal, but this is only a partial solution. There is a danger of removing redundancy to achieve maximum bit-rate reduction on the one hand, only to have to put it all back again in order to provide sufficient ruggedness to transmission errors.

In the system described here, the choice of DPCM predictor coefficients has been carefully controlled to minimise the subjective effects of transmission errors, whilst maintaining high prediction gain. A rapid decay of the impulse introduced by an error is required, rather than its integration at the decoder, as with simple DPCM systems. One solution is to introduce a 'leak' into the predictor by deliberately ensuring that its frequency response is less than unity at all frequencies. With simple predictors the prediction gain falls rapidly if the leak is sufficient to make the error decay short. However, with the complex mixed-field predictor described, greater control of its frequency response is possible and a very small leak may be introduced, having little effect on the prediction gain, but a dramatic effect on error-decay rate. Quantitatively, a good measure of the error performance of a DPCM system is gained from its stability margin, determined from a Nyquist plot of the open-loop frequency response of the decoder, i.e. that of the predictor. This is included in the computer optimisation procedure.

Fig. 13 (view picture-side of photographs) shows that, in contrast to a simple DPCM system

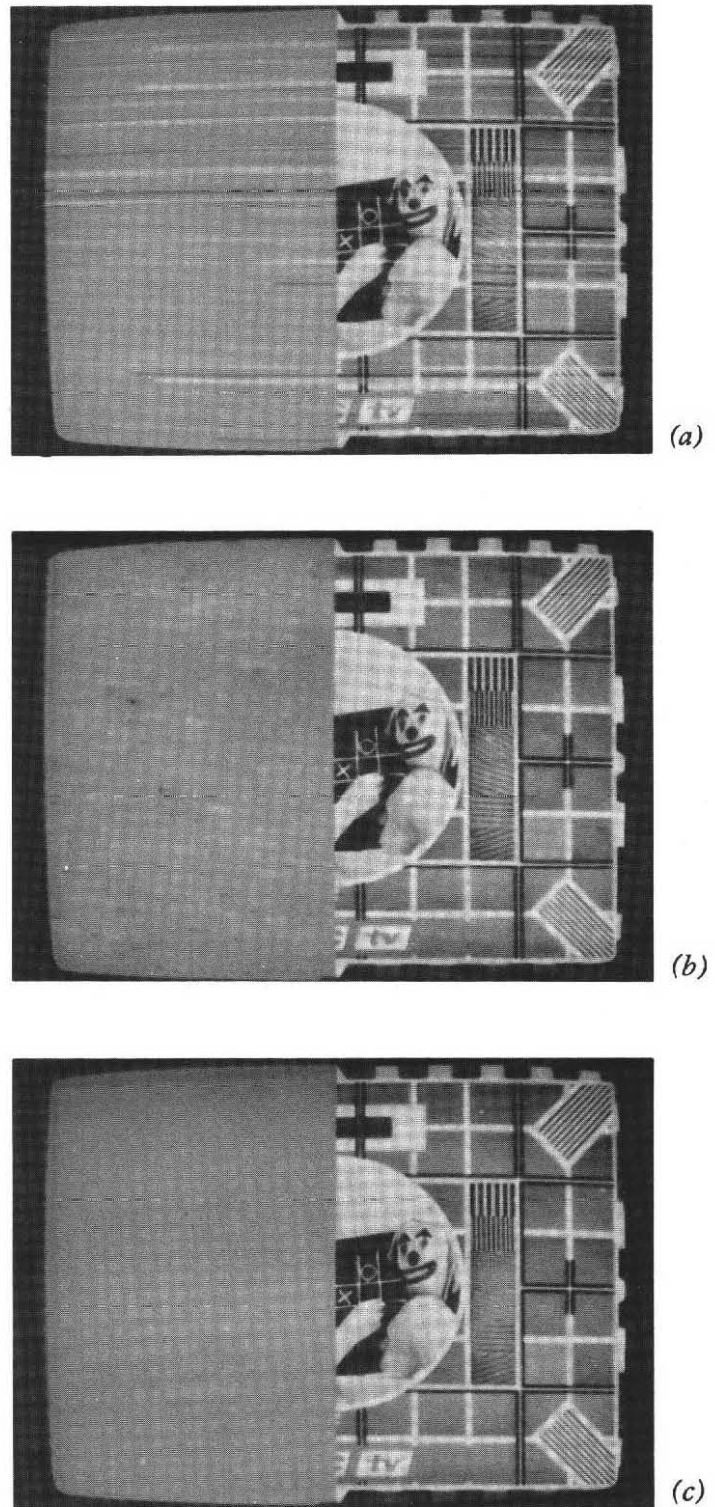


Fig. 13 — Effect of transmission errors at a bit error ratio of about  $10^{-4}$  (a split screen shows the errors in isolation, left, and the decoded picture, right. Note that the two-field exposure of the photographs has the effect of making the PCM errors (c) appear relatively less annoying than in reality).

(a) System using simple DPCM. (b) 34 Mbit/s system using complex DPCM. (c) PCM system.

having second-previous sample prediction (fig. 13a), the complex DPCM system with mixed-field prediction (fig. 13b), is almost as tolerant to transmission errors as PCM (fig. 13c). The bit-error ratio in the photographs is abnormally high, in excess of  $10^{-4}$ , whereas the random bit-error ratio at which errors are just perceptible is about  $10^{-7}$  for the 34 Mbit/s system.

In practice, it is expected that most terrestrial digital circuits (radio, line, and optical fibre) will be virtually error free most of the time, although some satellite circuits may exhibit a continuous bit-error ratio in the region of  $10^{-8}$ . However, with suitable error-correction coding, requiring an additional 6-7% of the video bit rate, protection to bit-error ratios up to about  $10^{-4}$  is quite feasible, even when the errors occur in short bursts, as is common with the digital modulation and scrambling techniques commonly used in digital transmission systems.

## 7. Transmission at 34 Mbit/s

Fig. 14 shows that use of the three bit-rate reduction techniques described, namely sub-Nyquist sampling, line- and field-blanking interval suppression, and DPCM, makes a total bit-rate saving of 71% possible when compared with conventional PCM coding of the composite PAL colour television signal.

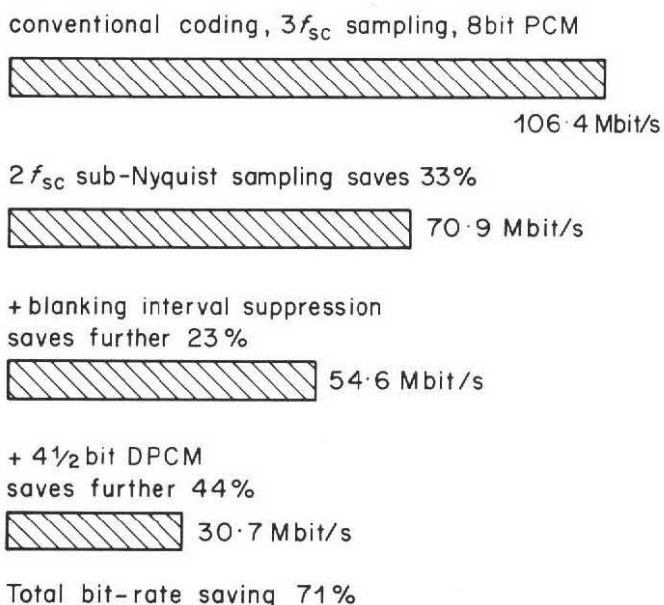


Fig. 14 – Video bit-rate savings.

A complete television transmission system additionally requires to convey the associated sound signal(s) and the field-interval signals (e.g.

CEEFAX, ICE), and Fig. 15 illustrates the composition of a system for transmission at the third-order multiplex rate of 34.368 Mbit/s.

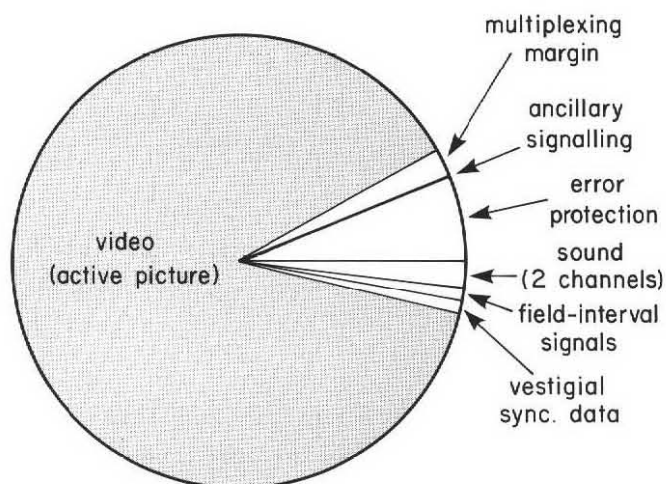


Fig. 15 – Division of the bit rate in the 34 Mbit/s digital television transmission system.

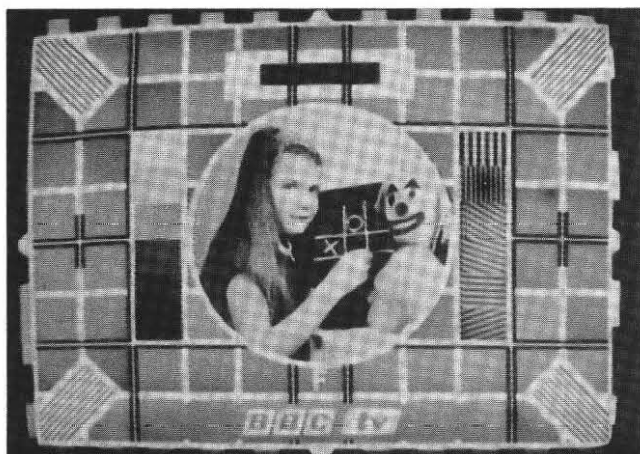
About 7% of the total bit rate is reserved for error protection of the television signals, to overcome the deleterious effects of errors which can occur on the transmission path. A small margin also exists for ancillary signalling (for engineering purposes) and for multiplexing the various signals together asynchronously. This includes framing and justification data required by the receiving terminal to demultiplex the various signals into their separate bit streams again.

Thus a complete digital broadcast television signal can be conveyed with a transmission capacity equivalent to only 480 digital telephone channels. In contrast, a system using conventional coding would occupy a capacity equivalent to about 1560 telephone channels.

## 8. Picture quality

Three bit-rate reduction techniques have been discussed, of which only two, sub-Nyquist sampling and DPCM, have any effect on picture quality. The impairments they introduce individually have already been considered: the performance of the 34 Mbit/s system as a whole will now be discussed. The pictures in Fig. 16 show that the impairments introduced are very small.

The system has been assessed in formal subjective tests. Test pictures (both moving and stationary) were shown to several different viewing



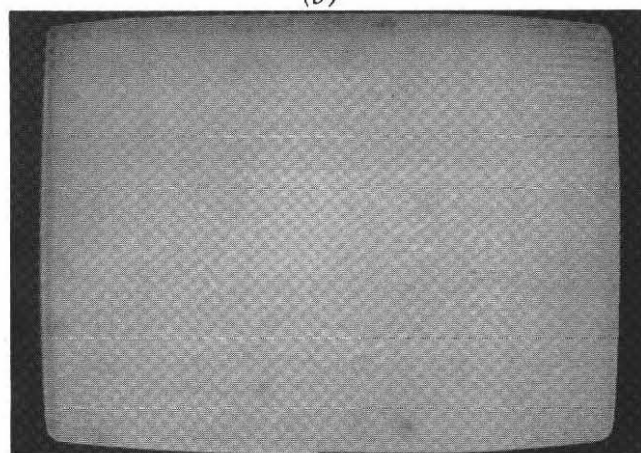
(a)



(b)

Fig. 16 — 34 Mbit/s system performance. The photographs are two-field exposures taken from a colour monitor and this 'freezes' the moving cross-colour patterns present in the PAL signal; this creates the patterns seen in the frequency bars and gives a jagged appearance to the vertical transitions in the picture photographs, but the reduction of cross-colour given by the 34 Mbit/s system can be discerned.

(a) Original picture. (b) 34 Mbit/s system picture.  
(c) 34 Mbit/s system total coding loss.



(c)

groups, each having six observers who were seated at four and six times picture height from the monitor. The viewing conditions were those of CCIR Rec. 500-1. The observers were all engineers most of whom were experienced in the critical assessment of television pictures.

Several test sessions were necessary in order to accommodate all the test pictures, observers and systems (the 34 Mbit/s system was not the only one tested). At the beginning of each test session the observers were told the type of impairment to expect and were asked to grade picture quality. A continuous grading scale was used, based on the CCIR 5-grade quality scale. It appeared on the test forms as illustrated in Fig. 17, and was marked by the observers according to their assessments.

A "double-stimulus" technique was used for tests. Each test session consisted of a series of presentations, each containing two test conditions, A and B, shown in the order A, B, A, B. One of the conditions in each presentation was an unprocessed analogue PAL picture, but whether it was A or B was changed at random through the

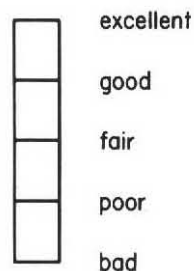


Fig. 17 — Appearance of grading scale on form used in subjective tests.

session, in an order unknown to the observers. After each presentation, the observers graded both conditions A and B according to the scale of Fig. 17. Each combination of particular conditions A and B with a particular picture occurred twice in the test session in random order.

The stationary picture signals were derived from a flying-spot 35mm slide scanner, using the following slides from the set recommended by the EBU: "Tree", "Boats", "Blackboard with toys", and also BBC Test Card F.

Two motion sequences were used: "Shirt" and "Trains". These were both specially recorded using a camera and an experimental digital YUV recorder, the signals only being coded into composite PAL form on replay. This arrangement was used because the recording was also intended for use in other experiments in which the original YUV components were necessary; it produced signals of very high quality.

Source signals, whether of stationary or moving pictures, were coded into composite PAL form using a PAL coder which incorporated a luminance notch.

The decision to use a notch followed tests made during the optimisation of the comb filters<sup>5</sup>; these indicated a clear preference, amounting to 0.5 grade, for the use of notched—over unnotched—PAL coding when viewing a colour monitor. Subsidiary tests, also using a colour monitor, have revealed, however, that the relative impairments introduced by the 34 Mbit/s system are substantially the same regardless of whether the luminance notch is used or, as is current practice, it

is not. The results for viewing a monochrome monitor are more complicated and are discussed in some detail in Refs. 5 & 6.

The "Shirt" sequence was very critical: a patterned shirt and finely-textured tie were moved laterally in simple harmonic motion. The pattern included lines at a variety of angles and occupied most of the screen. The momentary pauses at the extreme points of the displacement helped to reveal any additional defects introduced as a result of the motion.

The "Trains" sequence was also fairly critical, but less so than the "Shirt". It consisted of views of a model railway, with one moving train and other trains and a background which were stationary. It included zooming of the camera viewing angle. This sequence was much more representative of real programme material, including a variety of detail and movement directions.

The results of the tests are summarised in Tables 1 and 2 below.

*Table 1. Results of subjective tests using stationary pictures.  
18 observers were used, 9 seated at 4H and the other 9 at 6H (H = picture height).*

Test slide	Grading for Analogue PAL			Grading for 34 Mbit/s system		
	4H	6H	Mean	4H	6H	Mean
Test card F	3.81	3.92	3.87	3.57	3.76	3.67
Tree	3.78	3.83	3.81	3.24	3.55	3.40
Boats	3.90	4.05	3.98	3.66	3.89	3.78
Blackboard	3.85	4.00	3.93	3.55	3.87	3.71
Mean of four slides			3.90			3.64

*Table 2. Results of subjective tests using moving pictures.  
12 observers were used, 6 seated at 4H and the other 6 at 6H.*

Test sequence	Grading for Analogue PAL			Grading for 34 Mbit/s system		
	4H	6H	Mean	4H	6H	Mean
Shirt	3.55	4.00	3.78	3.16	3.61	3.38
Trains	3.14	3.67	3.40	3.08	3.62	3.35

The results confirm that the impairments introduced by the 34 Mbit/s system are generally very small. Using the system reduces the quality rating by a mean of 0.26 of a grade for the test slides, by a negligible 0.05 grade for the "Train" sequence, and by 0.4 grade for the "Shirt" sequence. Bearing in mind that the "Shirt" sequence was extremely critical and unrepresentative of most programme material these results are very good.

The results bring up two other points worthy of note. The quality grades given for the unprocessed PAL pictures were significantly less than 5. The observers were not told which pictures were the reference, unprocessed condition and thus graded them as they thought fit. The basic impairments of even the very best PAL pictures were thus considered quite significant by the observers, several of whom were acquainted with the quality obtained in direct RGB pictures. Secondly, viewers at 6H generally gave better grades than those at 4H but this applied to both original and 34 Mbit/s pictures and thus does not affect the conclusions.

The companion Reports<sup>5,6</sup> describe the more detailed assessment of the individual effects caused by sub-Nyquist sampling and d.p.c.m. coding.

Some other tests were held to assess the effects of transmission errors. These were of necessity somewhat informal because of shortage of staff at the time of the tests, and also because of the difficulty posed by the duration required. At low bit-error ratios the time for a presentation to contain a significant number of error events is inconveniently long. The test results suggest that the effect of transmission errors becomes "Perceptible, but not annoying" (grade 4 on the CCIR 5-point impairment scale) at a bit-error ratio (b.e.r) of 1 in  $10^6$ . Use of a simple error-correcting code (Wyner-Ash (16,15)<sup>19</sup>) raised this figure to nearly 1 in  $10^4$ .

Still better performance for the same redundancy could be obtained if the Reed-Solomon (63,59) code is used: the effects of errors should then remain imperceptible up to a b.e.r. of 1 in  $10^4$ .

## 9. Conclusions

When PAL television signals are coded into digital form they require a bit rate which is inconveniently high for transmission unless bit-rate reduction techniques are used. Three suitable techniques have been described:

- (a) blanking-interval removal,
- (b) sub-Nyquist sampling,
- and (c) differential pulse-code modulation.

A system has been devised which uses all these techniques in combination. It will carry a video signal, two high-quality sound signals, and other ancillary services within the standard bit rate of 34.368 Mbit/s, including the provision of error correction. The picture coding has been particularly tailored to the properties of the PAL video signal, thereby affording a substantial saving in bit rate without significant reduction of picture quality.

Subjective tests demonstrate that the system described maintains adequate picture quality for use in the distribution of broadcast signals. Sufficient error protection can be included to make the system compatible with the expected performance of proposed terrestrial transmission circuits.

Whether to use such a system remains to some extent a question of economics: the potential saving in transmission costs resulting from the reduction in bit rate must be balanced against the costs of provision and maintenance of the coding equipment. It may be that the optimum transmission rate will be of the order of 60 Mbit/s, and further development has therefore concentrated on that rate. Investigations are also in hand into component-based systems to satisfy the special requirements of contribution links.

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